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Entrepreneurship, Flexibility, and Policy Coordination: Taiwan's Computer Industry

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In just 15 years, Taiwan has emerged as a leading producer of hardware for nearly every major computer vendor in the world, despite little previous experience in high-technology industries. By 1995, Taiwan ranked fourth in the world in computer hardware production and exports through its strategy of being a "fast follower." Taiwan's success in the computer industry has been due to a coordinated government strategy to support private entrepreneurship by a large number of small, flexible, innovative companies. Taiwan's computer companies have responded rapidly and effectively to continuing changes in the international market and avoided many of the problems encountered by their counterparts in Japan and South Korea in recent years. They have done so by emphasizing close supplier relationships with multinational computer companies all over the world as a means of promoting exports and keeping apprised of market conditions. They continue to show great adaptability as Taiwan's computer industry moves toward diversification both upstream and downstream, full-service OEM (original equipment manufacturing) for multinationals, and industry consolidation for scale economies. The government has closely complemented the efforts of industry by carrying out research and development and transferring technology to the private sector, by conducting market intelligence for private sector use, and by providing engineering and technical manpower. As a result, Taiwan is probably Asia's best positioned country for continued success in the global computer industry.

Keywords Acer, computer industry original equipment manufacturers (OEM), industry, structure, Institute for the Information Industry, motherboard, peripheral, personal computer, Taiwan, Tatung, technology policy

In the past 15 years, Taiwan has emerged as a major player in the international computer industry. In 1980, Taiwan had no computer production to speak of, and showed little evidence of comparative advantage in high-technology industries such as information technology. Yet by 1995, Taiwanese companies produced over US\$17 billion worth of computer hardware [Market Intelligence Center/Institute for the Information Industry (MIC/III), 1995], and ranked first or second in the world in production of monitors, motherboards, notebook computers, keyboards, graphics cards, scanners, and mouse devices (MIC/III, 1995).

Taiwan benefited from entering the computer industry at the time of the personal computer revolution. The open PC architecture created by IBM in the 1980s lowered barriers for entry into the computer industry, both financially and technologically. Opportunities were created for Taiwanese companies to participate in the decentralized global production chain of the PC industry. Taiwan's computer industry initially reverse-engineered existing technologies to produce low-cost personal computers, peripherals and components. They subsequently developed their own design and process engineering capabilities to manufacture more complex, higher value-added products.

The evolution of Taiwan's computer industry is quite different from that of its East Asian neighbors. Japan's and Korea's computer industries are dominated by a few very large diversified conglomerates, while Singapore's industry consists mostly of subsidiaries of multinational corporations (MNCs). Taiwan's computer industry consists of thousands of dynamic small and medium-sized enterprises (SMEs), a few of which have grown into fairly large firms in recent years (e.g., Acer, First International Computer, and Mitac).

The growth of Taiwan's computer industry cannot be explained as a result of market forces alone. It is better seen as a result of a coordinated government effort to support the entrepreneurial efforts of a dynamic private sector. Since the designation of information technology as a "strategic" industry in 1981, a broad range of policy initiatives has been taken by government to support the computer industry, including incentives to the private

sector, demand stimulation through government procurement, training of computer professionals, support for R&D, and provision of market intelligence.

Taiwan's technology policies have been described as "diffusion oriented," with the "principal purpose [of] diffus[ing] technological capabilities throughout the industrial structure, thus facilitating the ongoing and mainly incremental adaptation to change" (Ergas, 1986). This focus on flexible adaptation to change is a hallmark of both government and company strategy in Taiwan. Taiwan's companies take advantage of a highly flexible, varied, and geographically clustered manufacturing structure to respond rapidly to market opportunities mainly created by U.S. and Japanese market leaders—the "fast follower" strategy. The government has compensated for the liabilities caused by the small size of companies by providing technology, capital, and market intelligence geared to the dynamics of the market. Government policies are developed with broad participation by the public and private sectors and are continuously modified to respond to changing conditions. The strategy for technology development differs from Japan and Korea, whose government policies encourage large firms to conduct R&D themselves or through government–industry consortia. In Taiwan, most firms lack the resources to undertake large R&D projects, so the government has taken a more direct role, creating public institutions that conduct research and disseminate technology to the private sector.

In the 1990s, Taiwan's computer makers have struggled to adapt to an international environment marked by brutal price competition, accelerating advances in technology, and increasing trade friction. So far, they have proven resilient and resourceful, and computer production has continued to grow rapidly, even as the Japanese and Korean computer industries have been badly battered. Taiwan's continued success is closely related to the structure of its computer industry, a structure well suited to the international PC industry with its complex web of supplier and subcontracting relationships. Taiwan's smaller companies have become tightly integrated into the global production chain of the PC industry, serving as suppliers and original equipment manufacturers for leading PC companies all over the world. Their flexible manufacturing systems and strong engineering capabilities have enabled them to respond quickly to market opportunities in a rapidly changing industry.

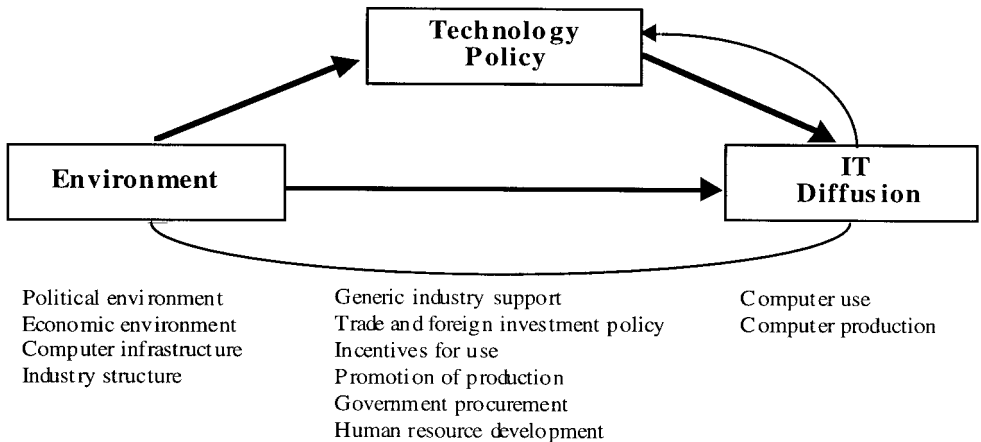


Figure 1. Framework for analysis.

This article presents a critical analysis of Taiwan's experience with computers using the framework presented in Figure 1. Moving from left to right, it posits that environmental variables such as the economy and industry structure influence computer production and use both directly and through the mediation of government technology policy. Environment and policy are closely interrelated, as policy choices alter the economy and industry structure, and these environmental factors in turn shape the range of policy choices available and the outcome of those choices for computer diffusion. Also, there is a feedback from computer diffusion to environment and policy. Over time, the success or failure of computer diffusion in the economy and of development of a national computer industry will change the environment and affect ensuing technology policy.

As shown in Figure 1, the environment consists of economic and industry factors that affect a country's ability to produce and use computers, as well as political factors that affect the policymaking process. Technology policy represents the strategic choices a nation makes about support for promotion of computer production and use. Computer diffusion includes the spread of computer use throughout the economy and the development of domestic hardware, software, and services industries. The framework is useful for analyzing both environmental and policy factors, and the interaction of the two, in explaining the evolution of computer production and use in a country.

The detailed analysis that follows is organized according to this framework. The first section discusses environmental factors affecting the use and production of computers. The next section recounts the history of technology policies related to the production and use of computers, considering the reasons why particular policy choices were made and the effects of those policies. The ensuing section looks at computer use and production in Taiwan over time and compares the level of use and production to selected other countries. Finally, the last section draws conclusions about Taiwan's experience with computers and its prospects for the future.

Environment

Political Environment

Taiwan, Republic of China (ROC), has had a centralized system of government with stable, one-party rule since the Kuomintang (KMT) Party took power in 1949. The removal of martial law in 1991 has not reduced political stability and the process of democratization has gone smoothly for the most part. If the KMT should be voted out in the future, the consequences would be uncertain. Taiwan's leading opposition party is a pro-independence party, and the Peoples' Republic of China (PRC) has stated its unwillingness to accept a declaration of independence by the ROC. Taiwan's relationship with the PRC is a key issue economically as well as politically. While the two governments still do not recognize each other's legitimacy, they have gradually opened up economic relations, and trade and investment have grown rapidly in recent years. China is potentially a huge market and, as will be seen later, a source of labor and resources for Taiwan. Thus, relations with the PRC will play an important role in determining Taiwan's economic future.

Economic Environment

Through the 1950s, Taiwan employed an import substitution strategy of industrialization, but the domestic market was soon saturated and the economy plagued with inefficient production and chronic trade deficits. In the early 1960s, Taiwan began opening its econ-

omy and promoting exports, and launched one of the great success stories in export-led growth. However, Taiwan's success was clearly not a victory of free-market economics, but one of a government-guided, market-oriented strategy. The government maintained control over foreign exchange allocation and manipulated the exchange rate to promote exports. Trade liberalization was rapid for imports of capital goods and intermediate inputs, but imports of consumer products were controlled for many years. By the 1970s, government policy had begun to focus on development of heavy industries such as steel, petrochemicals, and shipbuilding (Wade, 1990).

In the 1980s, the focus of industry promotion shifted to high-technology industries, particularly computers and semiconductors. The semiconductor industry was developed originally by state-owned enterprises spun off from government labs, while the computer industry was left to the private sector, with support from government. The shift to capital- and technology-intensive industry is reflected by the composition of Taiwan's export mix, as seen in Table 1. Between 1970 and 1994, labor- and raw-material-intensive exports (processed food, textiles and wood products) dropped from 52.1% to 20.6%, while capital- and technology-intensive exports (rubber and plastics, electronics, and metal manufactures) rose from 15.2% to 42%.

The government drafted a Six-Year National Development Plan for 1991–1996 with the aim of making Taiwan a major financial center, a regional transportation hub, and a leader in high technology in the western Pacific. The strategy outlined for achieving these economic and social objectives called for a substantial increase in government investment. The heart of the plan was a US\$300 billion infrastructure development program targeting transportation, communications, housing, energy, education, environment, and technology (*Business Week*, 1991). This investment was expected to increase domestic demand and reduce the trade surplus, which had become a source of international friction with the United States. It was also supposed to cut production costs and improve productivity by removing infrastructure bottlenecks. However, the high cost of the program concerned bankers and lawmakers, who feared the debt burden would be too heavy. The program was cut back in 1993, from NT\$8.2 trillion to NT\$6.4 trillion,¹ and from 779 projects to 634 (*Far Eastern Economic Review*, 1994).

Industry Structure. Taiwan's industrial structure consists of four major groups: small and medium-sized enterprises (SMEs), large private industry groups, state-owned enterprises

Table 1
Taiwan's export mix

	1970	1986	1994
Processed food	12.8%	5.1%	3.6%
Textiles	31.7%	18.3%	15.0%
Wood products	8.6%	4.4%	2.0%
Rubber and plastics	1.0%	9.4%	6.9%
Electronics	12.3%	22.3%	26.5%
Metal manufactures	1.9%	5.9%	8.6%

Note. From Clark (1989) for 1970 and 1986; 1994 data approximates Clark's categories, constructed from *Taiwan Statistical Data Book* (CEPD, 1995).

(SOEs), and subsidiaries of foreign multinational corporations (MNCs). There are 800,000 SMEs in Taiwan, accounting for 96.8% of establishments, 80% of new job creation, and 50% of total production in Taiwan (MOEA, 1993). In 1986, 65% of manufactured exports were produced by SMEs. In the electronics industry, 4435 new companies were established in just the period from 1981 to 1986 (Kajiware, 1993).

The prevalence of SMEs is not simply a factor of market forces. Instead it is a result of government policy choices. Between 1949 and 1958, tenant farmers were sold land that had been confiscated from Japanese colonists and bought from landlords under a land reform program (Clark, 1989). The former landlords were paid in government bonds and in shares of public companies, which served as a basis for their entry into industry. Many of the landlords subsequently became entrepreneurs in Taiwan's legions of small and medium-sized companies.

In the past, most SMEs were in labor-intensive industries such as textiles and simple electronics assembly, but many have been moving into more technology-intensive production. This segment of the industrial structure has provided great flexibility and entrepreneurial energy, but small firms are often undercapitalized and do not have the resources to make large investments in plant and equipment or research and development (Clark, 1989). This is especially true in Taiwan's electronics and computer industry. Of the 4000 plus firms in the industry, over 85% are registered with less than US\$2 million in capital (Coopers & Lybrand Consultants, 1995). In addition to the predominant SMEs, there are several large private industry groups, such as Tatung and Formosa Plastics. These are diversified industrial conglomerates, but are only a fraction of the size of their counterparts in Japan and Korea. Some of these groups are now major players in the computer industry.

Certain strategic sectors of the economy have been developed by state-owned enterprises. These include heavy industries and semiconductors, which require large investments to achieve economies of scale and reduce costs. The government decided that such industries were necessary to support the industrialization process, and were also important to national security. As such, it was necessary to develop domestic production, whether or not the private sector had the means to invest or was willing to take the risk. As the private sector has grown larger, the government has sold some of its interest in various SOEs, including several semiconductor companies.

Foreign investment has also played an important role in Taiwan's industrialization, especially in high-technology industries. From 1980 to 1987, foreign investment into Taiwan totaled US\$4.63 billion. Of the total, US\$1.42 billion came from the United States, US\$1.33 billion from Japan, and US\$470 million from overseas Chinese (Kajiware, 1993). Sixteen percent of this total went into the electronics industry. In 1985, the Ministry of Economic Affairs (MOEA) found that foreign MNCs accounted for 13% of total exports, and that the share of foreign companies in total exports was highest in electrical and electronics machinery at 39%. This figure has declined over time as domestic companies have displaced MNCs in the electronics industry, but the MNCs have made a critical, early contribution to the development of Taiwan's electronics and computer industries, both by investing and by sourcing from Taiwanese firms.

Computer Infrastructure

The production and use of computers depends on a supporting infrastructure of telecommunications networks, human resources, capital markets, research and development and complementary industries. Taiwan has a strong infrastructure, particularly in basic telecommunications services, human resources and complementary industries. It is some-

what weaker in advanced telecommunications, capital markets, and R&D, but the government has been investing heavily and making regulatory reforms to upgrade those areas.

Human Resources. Taiwan has made admirable progress in human resource development, and now ranks close to the developed countries in many categories, including literacy and secondary enrollment, as illustrated in Table 2. The pool of scientists and engineers doubled from 1984 to 1991, but is being taxed by the rapid growth of technology intensive industries. Skilled and semiskilled labor is in very short supply. The Council on Economic Planning and Development projects a shortage of roughly 120,000 unskilled and semiskilled workers by 1996.

Taiwan's universities produced 6533 bachelor's degrees in natural science and 8950 in engineering in 1990. This total of 15,483 is less than one-third of Korea's total, while Taiwan's population is about half of Korea's. Taiwan does better in advanced degrees, with 4011, compared to Korea's 7070. Taiwan is behind, proportionally, in the number of software engineers, as Taiwan's total is about 40% of Korea's.

Many of Taiwan's graduate students study in the United States, where 77% of Taiwanese students' doctoral degrees in natural science and engineering are earned. Many of them subsequently go to work for large U.S. firms such as AT&T and IBM. Even in 1991, 55% of Taiwanese who earned a doctorate in natural science and engineering in the United States planned to stay in the United States after graduation (NSF, 1993, p. 45). This caused a "brain drain" of Taiwanese professionals for many years. It is estimated that there are around 100,000 overseas Chinese working in the United States; 30,000 in Silicon Valley alone, and that 25% of the semiconductor design engineers in the United States are Chinese. The government has offered various incentives to induce Taiwanese nationals to return over the years, and the brain drain has begun to be reversed with considerable advantage for Taiwan. Many engineers and computer scientists have been returning to Taiwan since the mid-1980s for the opportunity to start their own companies or work for fast-growing Taiwanese firms. They often bring tacit knowledge and high-level technical and managerial experience from leading-edge U.S. companies when they do return. A leading example is Morris Chang, who recently retired at 75 from the presidency of TSMC semiconductor company and is considered the "father" of Taiwan's semiconductor industry. Chang went to the United States for graduate study, stayed there, and later became a vice-president at Texas Instruments and then president of General Instruments, both early leaders in the U.S. semiconductor industry. While at General Instruments, Chang helped to create about a dozen Taiwanese spin-off companies. He was subsequently invited to become the head of Taiwan's leading research institute, where he spearheaded efforts to develop a local semiconductor industry. Later, when Taiwan Semiconductor Manufacturing Company was spun off from the government lab, Chang was chosen to head the new company. Such examples are exceptional and few, but they have become part of industry lore, and their impact on the perceptions and motivations of Taiwanese scientists and engineers is substantial both at home and abroad.

Even those Taiwanese who remain in the United States are valuable Taiwan resources, providing links to U.S. markets and technology, consulting and moonlighting on product development, and doing market intelligence for Taiwanese firms and industry.

Research and Development, Technology Transfer. Taiwan has developed its industry mainly by applying technology transferred from abroad rather than by developing its own technology. While Taiwan's total R&D as a share of GDP was only slightly less than in Korea, private industry accounted for just 53.6% of R&D expenditures in Taiwan versus

Table 2
Human resource indicators for selected Pacific Rim nations

	Tertiary enrollment (% of 20–24 year olds) ^a	Number of scientists and engineers, 1988 ^{b-d}	Scientists and engineers per 10,000 workers ^{b,c}	Bachelor's degrees in science and engineering 1990 ^{b,c}	Master's and PhDs in science and engineering 1990 ^{b,c}	Number of professional software engineers ^e
United States	60	949,200	75.6	169,726	66,508	1,744,616
Japan	30	505,500 (1991)	74.9	106,508	36,549	850,000
Korea	37	70,500 (1990)	48.8	51,266	7,070	295,798
Taiwan	28	46,200 (1991)	27.1	15,483	4,011	121,800
Singapore	19	5,876	37.2	2,498	200	9,772
China	2	309,000	5.6	206,115	20,787	993,650

^a *UNDP (1991)*.

^b *PECC (1991)*.

^c *NSF (1993)*.

^d *ROC (1993a)*.

^e *Jones (1993)*.

Table 3
R&D expenditures

	R&D as percent of GDP	Industry as percent of total R&D
United States	2.67 (1991)	71.5
Japan	2.77 (1991)	76.7
Korea	1.91 (1990)	74.0
Taiwan	1.70 (1991)	53.6
Singapore	0.90 (1990)	54.2
China	0.70 (1990)	40.0 ^a

Note. From PECC (1991), ROC (1993a), and NSF (1993).

^aIncludes national enterprises.

74% in Korea (Table 3). The small size and low capitalization of most Taiwanese high technology firms make it difficult for them to do R&D independently. Consequently, the government has compensated for low levels of private R&D by supporting government-sponsored institutes, which conduct R&D and transfer technology to the private sector. Most recently, the government has begun to directly fund private-sector R&D by individual companies or by industry–research institute partnerships.

Of the NT\$95 billion spent on R&D in 1992, about one-fourth was spent on computer-related research (CEPD, 1995). With an emphasis on electronics and computer research, Taiwan has developed a strong technology base in those industries, and has been very successful in translating those capabilities into commercial products.

Telecommunications. The cost, quality, and penetration of telecommunications and the availability of advanced services are important to both computer production and use because they stimulate demand for computer products on the one hand, and support the computer industry's efficient operation on the other. Taiwan ranks ahead of Korea and Singapore and about even with Hong Kong in penetration of telephone access lines, but is behind Hong Kong and Singapore in cellular phones (Table 4).

Table 4
Telecommunications indicators

	Access lines per 100 population, 1991	Cellular phones per 100 population, 1994
United States	55.3	n.a.
Japan	47.2	1.5
Hong Kong	47.7	4.9
Taiwan	45.5	2.8
Singapore	38.7	4.7
Korea	38.2	1.0

Note. From Davidson et al. (1993) and Clifford (1994).

The Directorate General of Telecommunications (DGT) is the sole provider of basic telecom services. DGT has drafted laws that would split its regulatory and operational functions, with operations taken over by a newly created company. It would also open up value-added services to the private sector. However, the new company would still be government owned, and workers would not give up their civil service status, making cost reductions difficult. As of 1996, these reforms were still under debate in the legislature, with at least five different versions being championed by different interests (USDOC, 1994c; interview, DGT, 17 November 1995). The MOTC has opened up some services to the private sector, including cellular telephone, paging services, and Internet services. Development of the telecommunications network is a key element of the Six-Year National Development Plan of 1991–1996, and DGT has proposed a construction plan of US\$10.5 billion for 1994–1997. However, lack of progress on legislative reform is slowing the reduction of telecommunications costs and the development of advanced telecommunications services—keys to stimulating domestic demand for the computer industry.

Capital. Availability of capital is a small problem for the economy in general, but a big problem for Taiwan's computer industry. Taiwan's savings rate averaged about 32% of GDP in the 1980s, providing a plentiful supply of investment capital. However, domestic investment declined from 34% in 1980 to just 22% in 1989, reflecting a large outflow of capital. This may be explained by the relatively low financial returns from the highly competitive computer industry and by companies shifting production out of Taiwan as costs of production have increased.

In spite of the seemingly plentiful pool of capital available, Taiwan's manufacturers have a hard time financing investments in plant, equipment, and R&D. As put by one industry analyst:

Firms have to be big enough or small enough to get capital. If big enough, they can raise capital in the markets. But, it's getting tougher too. In the late eighties, if a PC company wanted to be listed on the Taiwan stock exchange, it had to have NT\$1 billion in revenues. In 1995, that amount has to be NT\$5 billion. Firms need more money today because they not only have to finance themselves, but their resellers and distributors too. If a firm is small enough, usually around NT\$0.5 billion, it can raise capital from friends and relatives. The government is encouraging small firms to go to the OTC market to raise money but there is not much success so far. It will take years to develop that market. (interview, Moun-Rong Lim, President, Hambrecht and Quist Taiwan Co., November 8, 1995).

The scale of the problem is illustrated by the fact that SMEs have been estimated to depend on informal capital markets (friends and family) for 30–40% of their credit (Baum, 1991).

Some analysts argue that the inefficiencies of the financial markets have been a reason for the inability of most SMEs to grow into larger companies. They see financial deregulation as the key to improving the functioning of capital markets and providing the necessary capital to upgrade the manufacturing sector. The banking industry was highly regulated and dominated by state-controlled banks until recently. In the early 1990s, 15 new banks were established, mostly backed by corporate conglomerates. The new private banks offer competition to state-owned banks and provide new sources of capital for industry.

Complementary Industries. An important element of the computer infrastructure is the presence of complementary industries such as consumer electronics and electronic components. Porter (1990) points out numerous examples of the importance of geographically

concentrated networks of complementary industries, such as California's Silicon Valley. Computer producers can benefit from manufacturing knowledge and technological capabilities that can be transferred from related industries, either within a company or by the movement of people between companies.

Taiwan has a large and diversified electronics industry that provides a tremendous supply infrastructure for its computer industry. Total electronics production in 1995 is estimated at US\$22.6 billion, or about 4% of GDP (*Yearbook of World Electronics Data*, 1995). Moreover, about 90% of the supply infrastructure is located within the 60-km geography from Taipei to Hsinchu—very similar to Silicon Valley. And that infrastructure is deep, with multiple sources for any upstream product category one might need, as illustrated in Table 5.

Taiwan has also been the host to substantial investment by MNCs, and Taiwan's electronics companies have served as suppliers, subcontractors, and original equipment manufacturers (OEMs) to multinational electronics companies; more recently, they are also serving as original design manufacturers (ODMs) for companies like Compaq and Packard-Bell.

Many computer companies in Taiwan started out in the consumer electronics industry, or were started by engineers from existing companies. The computer industry benefits from proximity to suppliers of components and from the presence of MNCs, who provide access to international markets, train local workers, and transfer technology into the country.

Technology Policy

The nature and effectiveness of technology policy are determined to a great extent by the structure of policymaking institutions. A centralized institutional structure can move quickly and achieve a high degree of policy coordination. This can be very effective in responding to economic challenges, as long as information flows are open and decisions are made in consultation with relevant participants in both the public and private sector.

Policy Institutions

Taiwan's institutional structure for economic and technology policy, which is shown in Figure 2, is highly centralized and has been able to effectively coordinate policy in close

Table 5
Downstream assemblers in Taiwan—Number of companies

Product category	1988	1989	1990	1991
PC systems	135	162	201	174
System boards	178	177	213	240
Keyboards	77	77	88	98
Power supplies	128	130	151	167
Printed circuit boards	114	140	144	145
ICs/ASICs	25	30	35	39
Cases/housing	17	18	22	38

Note. From Coopers & Lybrand Consultants (1995) (based on TEAMA membership directory count; a partial listing of all firms in Taiwan).

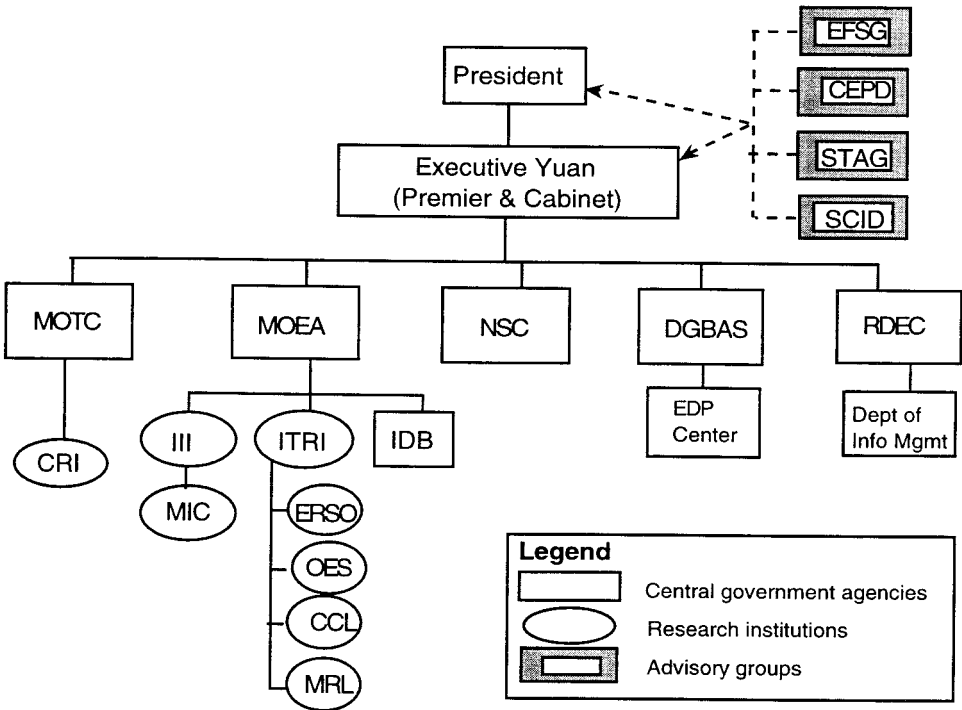


Figure 2. Structure of policy institutions in Taiwan.

consultation with the private sector. The key institutions are discussed next, with others briefly described in Table 6.

The president and premier have considerable control over economic policy. The Economic and Financial Special Group (EFSG) within the Cabinet serves as the economic staff for the president, deals with the most difficult economic issues, and has decisive influence over economic policy (Wade, 1990, p. 196). The EFSG consists of the Minister of Economic Affairs, Minister of Finance, Director General of the Budget Accounting and Statistics, Governor of the Central Bank, and one or two ministers without portfolio. The premier and his cabinet (Executive Yuan) are advised on economic matters by the Council for Economic Planning and Development (CEPD), whose duties also include formulation of economic plans and arbitration of disputes between ministries.

The leading ministry in charge of economic development and industrial policy is the Ministry of Economic Affairs (MOEA). Within MOEA, industrial policy is primarily implemented by the Industrial Development Bureau (IDB). IDB turns the broad plans of the CEPD and cabinet into detailed sectoral plans. It makes lists of items to receive fiscal incentives, encourages firms to buy from domestic suppliers, and provides administrative guidance to firms in industries targeted for promotion (Wade, 1990). Also, IDB is in charge of developing industrial parks such as the Hsinchu Science-Based Industrial Park.

MOEA has a major role in technology policy, providing incentives for private sector R&D, promoting technology imports, and supporting a number of research organizations. MOEA spent about US\$430 million on R&D in 1992 (MOEA, 1992). The Industrial Technology Research Institute (ITRI) was established in 1973 under MOEA's supervi-

Table 6
Other computer policy institutions

-
- The Ministry of Transportation and Communications (MOTC) is responsible for telecommunications policy, and oversees the Communications Research Institute, which is concerned with advanced telecommunications research.
 - The Science and Technology Advisory Group (STAG) coordinates science and technology policy with overall economic policy and guides the National Science and Technology Program. The STAG consists of foreign advisors who meet twice a year to discuss proposals for new technology initiatives in Taiwan and world developments in R&D.
 - The National Science Council (NSC) recommends national scientific and technology policy and coordinates R&D activities. NSC supports academic research and training of scientific personnel (Richeson, 1988). The government also makes heavy use of consultants and task forces, made up of specialists from universities, research institutes and consulting firms.
 - The Steering Committee for Information Development (SCID) in the Executive Yuan coordinates government computerization plans. Ministries and agencies develop information plans to support their own administrative needs and implement them with the assistance of the SCID and III.
 - The Research and Development Evaluation Commission (RDEC) of the Executive Yuan conducts research on the computer needs of government agencies and coordinates local government computerization efforts (ROC, 1993b).
 - The Directorate-General of Budget, Accounts and Statistics (DGBAS) administers the budget process, matching funding to priorities.
 - The Electronic Data Processing Center of DGBAS conducts evaluations and surveys of the computer needs of government agencies.
 - The Information Development Promotion Subcommittee within the Executive Yuan provides advice on computer policy and has been responsible for drafting Taiwan's national information infrastructure (NII) plans.
-

Note. These institutions, shown earlier in Figure 2, are also part of the complex institutional structure for policymaking and implementation related to economic development and technology policy.

sion to conduct research on civilian industrial technologies. In 1993, ITRI had a budget of over US\$500 million (Manasco, 1994), two-thirds from government and one-third from industry.

One of ITRI's branches is the Electronics Research and Service Organization (ERSO), formed in 1974. ERSO carries out research on semiconductors and computer hardware technologies, which are commercialized either by state-owned enterprises or the private sector. Along with conducting its own R&D, ERSO also facilitates technology transfer by licensing foreign technologies and then sublicensing them to domestic firms. This eliminates price-raising competition among firms for the same technology and puts all firms at the same starting point (Wade, 1990).

Three other ITRI subsidiaries conduct computer-related research. The Computer and Communications Research Laboratories (CCL) researches integration of computer, communication, and consumer electronics technologies. The Opto-Electronic and Systems Laboratories (OES) conducts R&D on optical disk storage, image processing, and semiconductors. The Materials Research Laboratories (MRL) develops materials for electronics and opto-electronic applications (Manasco, 1994). In the past, the approach of ITRI and its subsidiaries was to develop a prototype of a new technology and transfer it to industry. That approach is changing because the capabilities of industry are greater. The new model is to have research institutes and industry work together closely from the beginning of a project (interview, R. Yang, 1993).

The Institute for Information Industries (III), also under MOEA, was formed in 1979 to oversee policy related to software, services, and computer use. III designs and devel-

ops systems and networks for government agencies and supports training, technology transfer, and market intelligence for the computer industry. III also conducts R&D in software, passing the results to the domestic software industry. Within III, the Market Intelligence Center (MIC) provides market research for the computer industry. III has a staff of 1200 people, 80% of which are professionals (III, 1993).

These government institutions frequently consult with industry associations such as the Taipei Computer Association, Software Industry Development Association, Electronics Industry Development Association, and Computer Industry Development Association, and with individual firms that are considered industry leaders such as Acer, Tatung, and MITAC. The aim is to understand industry problems, float plans for industry comment, promote industry participation in government support programs, evaluate industry proposals for government funding, and monitor firm and industry performance under government grants, loans, and subsidies. For the most part, these relationships with industry are cooperative and supportive rather than competitive and adversarial, with the result that most efforts are aimed at achieving positive outcomes even when projects do not go as expected.

Thus, Taiwan has had a well-defined structure for policy formulation, coordination, and implementation. Broad economic policy guidance comes from the EFSG and CEPD. Actual implementation of industrial development and technology policy is centralized within the MOEA and its affiliates. Frequent consultation occurs at various levels with international experts, industry associations, and industry leaders in this institutional structure. This chain of command has been empowered by the political leadership to design and implement a coordinated policy approach and has enabled Taiwan to develop a coherent strategy for its computer sector. However, there are some concerns that the government's ability to coordinate policy is eroding as democracy takes hold and competing interests gain influence in the policymaking process. Also, as private companies gain confidence in their own capabilities, they are becoming less responsive to government direction.

Technology Promotion

The government has actively promoted the development of high-technology industries in Taiwan. A key part of that strategy is the Hsinchu Science-Based Industrial Park, opened in 1980. The park is located close to ITRI laboratories and the government has taken up to a 49% equity position in spinoffs from ITRI to get ventures off the ground (Wade, 1990, p. 98). Efforts are underway to convert Hsinchu into a "Science City" modeled on the Research Triangle in North Carolina and Japan's Tsukuba "Science City." An important goal for the Science City is to attract overseas Chinese to return to Taiwan and set up high-tech firms. As of 1989, a third of the firms in the Hsinchu park had been established by overseas Chinese (Dahlman, 1992). Investors have been wooed by the development of a fiber-optic telecommunications network, a supercomputing center, and housing and other amenities (*Electronic Business Asia*, 1991).

In 1992, Taiwan ran a US\$4.7 billion trade deficit with Japan in electronics. The computer industry depends on Japanese suppliers of LCD panels, batteries, and DRAMs, and U.S. suppliers of microprocessors. Some PC makers accuse Japanese companies of setting arbitrary limits on supplies of components or raising prices to reduce the profit margin of Taiwanese companies (*Electronic Business Asia*, 1992). Still, Taiwan maintains reasonably good economic relations with Japan. Japanese companies have transferred trailing-edge technologies to Taiwanese companies, allowing the Taiwanese to pursue their "fast-

follower" strategy. For instance, when Japanese monitor makers moved up to 17-inch monitors, they transferred technology for 14- and 15-inch units to Taiwan, allowing the Taiwanese to take over much of those market segments. Taiwan's trade deficit in computers with Japan has declined recently as Japan has begun importing more components and peripherals from Taiwan. However, Taiwan remains concerned about its dependence on Japan for key components such as LCD panels, and for sophisticated production equipment.

One answer has been a concerted effort to develop domestic capabilities in semiconductor production. The government has developed semiconductor technology at ERSO and supported the entry of domestic firms into the DRAM industry (Table 7). Taiwan's computer industry should benefit from a reliable domestic supply of semiconductors, and the semiconductor industry can also count on a dependable market for its products. The integration of computers and semiconductors is supported by strong design capabilities in both industries. This means that domestic companies can benefit from cooperation in the design of chips, circuit boards, and final systems. A number of chip factories are already operating or are under construction and as many as 15 are planned.

Computer Policy

Taiwan's national computer policy was spearheaded in the late 1970s by K. T. Li, who was minister without portfolio but very influential in government and industry, having been Minister of Economic Affairs, Minister of Finance, a potential candidate for president, and a close advisor to the then president of Taiwan. Taiwan's policy has promoted both production and use of computers from the beginning, but has focused primarily on production. In 1980 information industries were designated as "strategic industries" by the Ministry of Economic Affairs, which made them eligible for a host of government subsidies and other assistance. Plans for advancement of the industry were laid out in the Sectoral Development Plan for the Information Industry, 1980–1989. The objectives of the Sectoral Development Plan were to promote the domestic use of computers, to create a market for the local information industry, and to develop export-oriented computer production. The promotion of use was linked to creating demand for local products. According to the director of the Promotion and Services Division of III, "The computerization of government agencies is basically a subordinate measure to the government's policy for developing the information industry, aiming to expand the domestic market" (Cherng & Lin, 1992).

Table 7
Taiwanese firms in the DRAM industry

-
- A joint venture of Acer and Texas Instruments, using TI's technology.
 - Mosel-Vitelc, a subsidiary of the U.S. company Vitelic, using technology from the Japanese firm Oki.
 - Nanya Plastics, a private firm also using technology from Oki.
 - Formosa Plastics, part of a large state-owned petrochemical conglomerate, using technology from Toshiba and Siemens.
 - Umax, a private company known for making computer scanners, using technology from Mitsubishi.
 - Taiwan Semiconductor Manufacturing Corporations (TSMC), owned jointly by the electronics multinational Philips, the Taiwanese government, and private investors.
 - Vanguard, a new venture supported by US\$68 in government investment, is a subsidiary of TSMC formed when TSMC bought ITRI's submicron laboratory in 1995.
-

Promotion of Computer Production. Government promotion of the computer industry has taken the form of subsidies, R&D investment, technology diffusion, computer skills training, trade and foreign investment policies, and alliances with foreign corporations.

Industry Subsidy. As of 1987, computer companies represented 28% of the total number of companies receiving assistance under the Strategic Industry Assistance Program (Richeson, 1988). This assistance included consultancy and training to managers in areas such as quality control and assurance and production management, as well as technical assistance for R&D, automation, and software design. In addition, as of 1987, the program had provided low-interest loans totaling over US\$50 million to computer hardware and software companies (San, 1990).

Research and Development and Technology Diffusion. Government R&D efforts in computer hardware have been led by ERSO. ERSO's task is to develop technology for the hardware industry, particularly in integrated circuits, and diffuse the technology through licensing agreements and establishing new spin-off companies. For example, six semiconductor companies were spun off by ERSO in the 1980s. Other ERSO projects include the development of prototypes for a superminicomputer system and a RISC-based engineering workstation, artificial intelligence, and parallel processing. ERSO also developed a version of the basic input-output system (BIOS) for the IBM-PC that was used by Taiwanese companies to produce IBM-compatible PCs.

The Computer and Communication Research Laboratory (CCL) took the lead in helping PC makers get into notebook production. CCL took on much of the commercialization work itself, bringing in as many firms as possible and creating one set of design and price criteria.

Tax incentives are available to encourage private sector R&D. R&D expenses can be deducted from taxable income if a firm meets minimum R&D input levels or contributes to a government fund for collective R&D projects.

Skills Development. Training in computer skills is carried out at multiple levels, mainly by universities and III, but also by elementary and secondary schools and private training schools. University education has stressed engineering fields, especially electronics, computer, and software engineering. Graduates of these programs are said to work well in computer companies, but less well in user industries, because they lack knowledge of business systems. Consequently, the government is promoting establishment of management information systems (MIS) programs in business schools to meet the need for business analysts (interview, M. Wang, 1993).

III has focused on special programs for in-service training in electronics and computer skills. One program provides training for entry- and middle-level government personnel to prepare them to work at government MIS installations. Another program is a 5-year plan to train at least 1000 government employees annually in end-user computing courses. Still another program trains teachers at elementary and secondary schools so they can teach basic computer concepts in the newly provided computer labs at each of 3000 individual schools (Dahlman, 1992).

The government has offered courses in information science for students majoring in fields other than computer science and has increased the number of university computer science departments and MIS programs. It has introduced information science to the senior high school curriculum, established at least one computer room for every school, and subsidized the offering of computer courses at the junior high level. Through a partnership between IBM and III, a Software Engineering Institute was established offering management and technical courses for executives and professionals (Richeson, 1988).

Trade and Foreign Investment Policy. While import controls were used in the past to promote consumer electronics production, the computer industry has been promoted while maintaining an open import policy. Foreign investments receive the same incentives and privileges as domestic investments. Foreign investors may have 100% equity in investments in Taiwan and may convert and remit all profits and interest. Until 1990, investors received a 5-year business income tax holiday, a maximum income tax liability of 20% after the tax holiday, exemption from tariffs on machinery imports, and exemption from business tax on exports.

Alliance with Multinational Corporations. An important part of Taiwan's computer strategy is the development of alliances with multinational corporations (MNCs) to gain access to technology and markets. An early example was the Neotech Development Corporation (NDC). NDC was established in 1983 by IBM and III to provide software development services to IBM. From 1983 to 1988, IBM paid US\$17 million to NDC for application software.

Another joint effort between IBM and III is International Integrated System Inc. (IIS), established in 1988. III provided US\$3.5 million and 70 software designers and IBM provided technical support. Unlike NDC, IIS does not have to provide services for IBM exclusively. In 1992, IBM and III agreed to merge NDC and IIS into a single company called Integrated Systems Development Corp. (ISDC), owned by IBM, III, and the ISDC employees. It is hoped that ISDC will have the size and technical ability to compete in the international market (Hou & San, 1993).

The software industry lacks marketing and distribution channels abroad and has limited experience in developing packaged software that can be exported. Consequently, it must work with multinationals to develop products for export. III has signed agreements with U.S. computer firms to commercialize some of its large-scale projects in the Asia market. These include a Chinese input-output system licensed to IBM and a joint venture with Hewlett-Packard to develop software for the Asian market (Wade, 1990). III also works with Microsoft developing Chinese-language applications for MS/DOS and converting English programs into Chinese (*Electronic Business Asia*, 1991). Microsoft developed the Chinese version of Windows 3.0 in Taiwan, but moved its development of Windows 95 to the mainland after pressure from the PRC government.

Provision of Market Information. The Market Intelligence Centre (MIC) of III is the key agency responsible for gathering and distributing market information to the computer industry. The MIC makes quarterly forecasts, produces monthly market reports, holds frequent industry seminars, and cooperates with industry associations to identify and satisfy market intelligence needs. MIC provides more specialized information than the large market research firms such as International Data Corporation (IDC) and Dataquest. As put by one MIC analyst, "IDC and Dataquest usually report market information about the top nine companies and then 'all others.' We focus on the 'all others.' Also, we focus on specific industry segments like monitors or motherboards and on the short- to mid-term (1–2 years) rather than the long term. We respond to questions that industry needs answers to now."

Taiwan's SMEs lack the expertise and money to collect or buy on their own the market intelligence provided by MIC. Thus, MIC plays a critical role in collating information developed by other industry watchers, collecting its own information, supplying information at reduced costs (about US\$5,000 per year vs. US\$40,000 per year in the U.S. from private industry watchers), and supporting the export activities of Taiwan's computer industry.

Software Industry Promotion. Since the early 1990s, computer policy in Taiwan has been shifting more toward the software and services industries, which are the fastest growing

segments of the computer industry, and where Taiwan is still relatively weak compared to hardware production. In 1989, III started the Software Engineering Environment Development (SEED) project, which lasted until 1992. The goal of the SEED project was to create a distributed software development environment and provide an information network where information, tools, and standards for software development would be available to developers throughout the country.

In 1992, the Industrial Development Bureau (IDB) and III were given responsibility to develop a 5-year plan for the software industry with a target of reaching US\$3.5 billion in output by 1997, with 20% of that total coming from exports (Kumar, 1993). The plan targets development of Chinese-language software for the domestic and export markets, selective development of packaged software products, and promotion of the systems integration business. The government's role in promoting the industry includes (III, 1992; interview, Sam Shen, 1995):

- Making competitive awards under an R&D grant and loan program for software development projects with potential for export. About 15 awards averaging NT\$3 million had been made by the end of 1995.
- Using domestic large-scale system projects to help local companies to develop systems integration capability.
- Introducing key technologies and helping local companies develop technology. Included here are projects to develop object-oriented technology, integrated CASE tools, and a software modification and validation center to develop quality assurance models.
- Training software personnel and cultivating the talents of advanced technology and program managers.
- Providing facilities for software development and accelerating development of computerization standards. Chief among the facilities is the creation of software parks in Taipei, Taichung, and Tainan.

Through these efforts the government hopes to increase the productivity of software professionals by providing them with necessary tools and standards. It also hopes to increase the average size of software and systems integration firms to enlarge their operational scale and strengthen their corporate structure. And it hopes to increase the amount of software that is exported to other countries. Experience with the program thus far indicates that a critical unanticipated need is the development of business knowledge and skills among software engineers, including general management and packaging, distribution, and marketing for export.

Nankang Software Park. The first software park being built is the Nankang Software Park in the new Economic and Trade Park being developed by the City of Taipei and the MOEA. The goal of the park is to provide a low-cost, supportive environment for export-oriented software companies. The initial target markets will be China, Hong Kong, Singapore, and the Chinese communities in Malaysia, Indonesia, Thailand, and elsewhere.

The park provides an integrated infrastructure for software development, testing, packaging, and distribution. There are also shared resources such as hardware, systems engineering tools, software validation services, distribution channels, legal services, and international marketing facilities. Its infrastructure includes a fiber optic network, emergency power, and power cogeneration. The full services of III will be relocated to the park, with the exception of top staff (interviews, C. N. Liu, 1993, 1995). MNCs are invited into the park to engage in joint ventures or to offer specific technologies. It is hoped that domestic companies will form alliances with MNCs and develop Chinese-language versions of their software.

Small Business Software Development. The Small and Medium Enterprises Bureau of MOEA is subsidizing software development for 40 types of small businesses (defined as having less than 70 employees and less than US\$200,000 in capital) ranging from laundries to bicycle shops to karaoke bars. The idea is to develop the local market for software, to test products in that market, and eventually to export the software products to Chinese communities in other countries. The market in Taiwan is viewed as too small to support the software industry, but it can serve as an important base for developing software for export. One problem for the industry has been the government's policy of developing software itself and giving it away to businesses to encourage them to use computers, thereby limiting the local market for commercial software. This is avoided in the small business software project by contracting with commercial software firms to develop the packages.

The Science and Technology Advisory Group has proposed putting up NT\$7 billion to support the software industry. III developed a plan under which most of the money would go to III, which the industry views as self-serving. The Software Industry Development Association says the money should go to efforts such as improving retail channels, providing better microlevel market intelligence on the software market, providing patient venture capital, and developing strategic alliances with foreign companies (interview, A. T. S. Hwa, 1993).

Promoting Computer Use

In the past, computer use has not received as much government attention as production. This is changing now, as there is an increasing awareness of the importance of application of computers to other industry sectors to improve productivity and maintain competitiveness. The government is attempting to promote computerization in both the private and public sector. Promotion of computer use and development of the domestic software industry are seen as closely linked. Encouraging domestic computer use will provide a market for the software industry, and developing locally oriented Chinese-language software will encourage computer use.

In 1990, the MOEA appointed the ROC Software Association to implement a Five-Year Industrial Computerization Promotion Plan. A team was organized to help 480 manufacturers to prepare information systems (IS) plans and to provide consulting services for other firms already in the process of computerizing (Wang, 1994). In 1991, the Small and Medium Enterprises Bureau of MOEA appointed information systems (IS) experts to conduct diagnoses of IS needs at 196 small firms and provide consulting to those asking for assistance. The government offers a 50% subsidy for expenses under US\$6,000 and makes low-interest loans available for small firms to buy hardware and software (Wang, 1994). In addition, the government's plans to develop vertical applications for small business sectors should make it easier for small businesses to computerize by avoiding the costs of creating custom applications.

Computer Use in Government. Government historically has been the largest user of computers in Taiwan (see Figure 5). Computer procurement policy goals are quite different for hardware and software. For hardware, procurement policies are aimed at getting the best performance at the lowest price and there is no explicit policy to buy local products. However, when it comes to PCs one local observer said, "It is easier to sell ice to an Eskimo than to sell a foreign PC in Taiwan. About 90% of the PCs used in Taiwan are made in Taiwan" (interview, 1995). For software procurement, since 1986 there have

been explicit “buy local” policies to promote the local software industry (Cherng & Lin, 1992).

In 1983, the government developed a plan for the creation of a Nationwide Administrative Information Functional System. In 1993, the government released a White Paper on Government Computerisation prepared by a task force in the Steering Committee for Information Development of the Executive Yuan (ROC, 1993b). The White Paper recommended expanding government computer use through the development of strategic national information systems projects. Six strategic national information projects are under development, with spending projected at US\$1 billion over 5 years. They are the Household Registry and Conscription Administration Information System, Land-Use Information Management System, National Geographic Information System, Cargo Clearance Automation Plan, Medical/Health Care Information System, and National Health Insurance Information System.

Management of government information systems projects and development of software for those projects have been led by III and the relevant agencies. III takes on most major government software development jobs itself, rather than directing them to the private sector. This is partly because the government agencies feel more confident working with III than with private software houses, who may lack the financial resources, skills, or experience to carry a job to completion.

Policy Issue: The Role of Government and Industry

In spite of their impressive track records, the key computer policy institutions in Taiwan have increasingly come under attack for taking too large a role in the development of new technologies and for competing with the private sector (Manasco, 1994). Industry executives and legislators have complained that institutions like ITRI receive too much of Taiwan’s R&D money and that ITRI’s efforts benefit big companies disproportionately. Others say the ITRI’s researchers do not understand the market and are not aggressive enough in commercializing their work. Still others complain that ITRI goes too far in commercializing its research and that it should bring in private investors at earlier stages of development.

ITRI was criticized for allowing over 40 companies into a consortium to set notebook computer standards and develop prototypes. This led to price wars and most members of the consortium dropping out of the notebook market. ITRI Chairman Morris Chang even admitted the mistake. “It was done to raise the technology level of more companies, but without regard to the economic dynamics” (Manasco, 1994). Some industry leaders, such as Acer CEO Stan Shih, have acknowledged ITRI’s importance in the past, but now argue for its breakup and privatization. However, there are fears that it would be a mistake to break up the leading independent research facility in Taiwan.

So far, the government has gone as far as reducing ITRI’s budget slightly for 1994 after nearly doubling it between 1989 and 1993. This forces ITRI to look more to industry, which now provides one-third of its funding. ITRI has responded to the criticism by announcing it would shift its emphasis more to precompetitive research and by establishing nine industry advisory committees to better understand the needs of industry.

Similar complaints have been heard about III. Because of its size, experience, and “deep pockets,” III gets a large share of government software development contracts. This is resented by the private software houses, who are in competition with III for projects and must live within project budgets. There are some who feel III should subcontract more of its work to the private sector, and there is even discussion about dividing III

up into several software companies. III officials do not want to see such a spin-off as they consider themselves part of the government. III has begun to change its role by concentrating more on project planning and management while giving more opportunities to the private sector. In the past, III has run into problems with subcontracting, as private-sector companies were unable to complete jobs and III had to take over. However, as Taiwan's software companies mature and gain capabilities, III is expected to evolve toward a staff and policy function rather than an operational role.

The role of government in technology policy is in transition. While Taiwanese officials are satisfied with past efforts to improve Taiwan's technological capabilities, they now want private industry to do more R&D. A key target of the Ten-Year Science and Technology Plan (1986–1995) was to increase the private sector's share of R&D from 40% to 60% of total spending (Hou & San, 1993). The actual private sector share of R&D was 48% for 1992, the latest reported date (CEPD, 1995). One approach is to spin off commercial enterprises from ITRI as has been done in the semiconductor industry.

Future Computer Policy: National Information Infrastructure

In 1994, Premier Lien Chan announced the establishment of a national information infrastructure (NII) task force to coordinate Taiwan's NII development efforts (USDOC, 1994c). The task force is charged with implementing telecommunications privatization, supporting R&D, improving wireless communications, and establishing standards for network-to-network compatibility. Taiwan is following the lead of Singapore, the United States, and others in developing NII plans with the goal of improving productivity in manufacturing, commerce, government, and education, and eventually to providing new information services to households.

Taiwan's NII plans go beyond infrastructure development, however. Construction of the NII is expected to expand demand for the computer hardware industry and to help develop the software and telecommunications equipment industries (USDOC, 1994c). The notion of building infrastructure and encouraging use in order to promote domestic production is a continuing theme of Taiwanese computer policy. By linking production, use, infrastructure, and R&D, the Taiwanese government is hoping to solidify Taiwan's position as a world leader in the electronics and information industries.

Computer Sector

Production

Electronics production in Taiwan was started by Japanese and American multinationals who set up assembly operations in the 1960s to take advantage of Taiwan's low-cost labor and facilities. Many of Taiwan's electronics manufacturers were started as spin-offs of these multinationals, while other companies sprung up to supply components. Many local entrepreneurs acquired management and technical skills working for, or selling to, MNCs. The first entrants into the computer industry were companies making unauthorized clones of the Apple II computer in the late 1970s. By the early 1980s, many Taiwanese electronics companies had shifted out of consumer electronics and were producing PC hardware. Some made components and peripherals such as cables, power supplies, keyboards and monitors, while others moved into PC assembly. As they gained experience and manufacturing capabilities, they shifted into more complex products such as motherboards, graphics cards, scanners, and eventually notebook computers. These

companies tended to move into new designs of existing products or new product lines altogether in response to new profit opportunities (Levy & Kuo, 1991). Most successful domestic producers started very small and grew rapidly. Those that failed in one product line often regrouped and tried again. With low upfront investments in production facilities, the cost of failing was low, and an entrepreneur could start over with another small investment.

Production by foreign MNCs played an important role in the early development of Taiwan's PC industry, but domestic companies surpassed foreign subsidiaries in PC production by 1990. More important in the long run was MNC sourcing of components and contracting with local firms for original equipment manufacturing. By 1995, Taiwan ranked fourth in the world in computer production and computer exports (*Yearbook of World Electronics Data*, 1995). Figure 3 shows the phenomenal growth of hardware production from 1985 to 1995.

In 1994, Taiwanese companies ranked first in the world in production of monitors (56% of world market), motherboards (80%), switching power supplies (31%), image scanners (61%), mice (80%), and keyboards (52%). They ranked second in notebook computers (28%) and produced 8% of the world's desktop PCs (Table 8). While production has grown rapidly in each of these categories, labor-intensive products are increasingly being manufactured offshore in China and Southeast Asia. These products include monitors, motherboards, power supplies, graphics cards, mice, and keyboards (Table 8).

Ninety-three percent of all Taiwanese hardware production is exported (USDOC, 1994b). There is heavy dependence on original equipment manufacturing, which actually increased from 31% of total PC output in 1991 to 46% in 1992. In 1991, 49% of Taiwan's exports of PCs and monitors were of self-owned brands, 46% were exported on an OEM basis to multinational corporations, and the remaining 5% were sales by foreign-owned firms producing in Taiwan. This illustrates the degree to which Taiwan relies on links to multinational corporations (51% of exports were by or through MNCs), but also

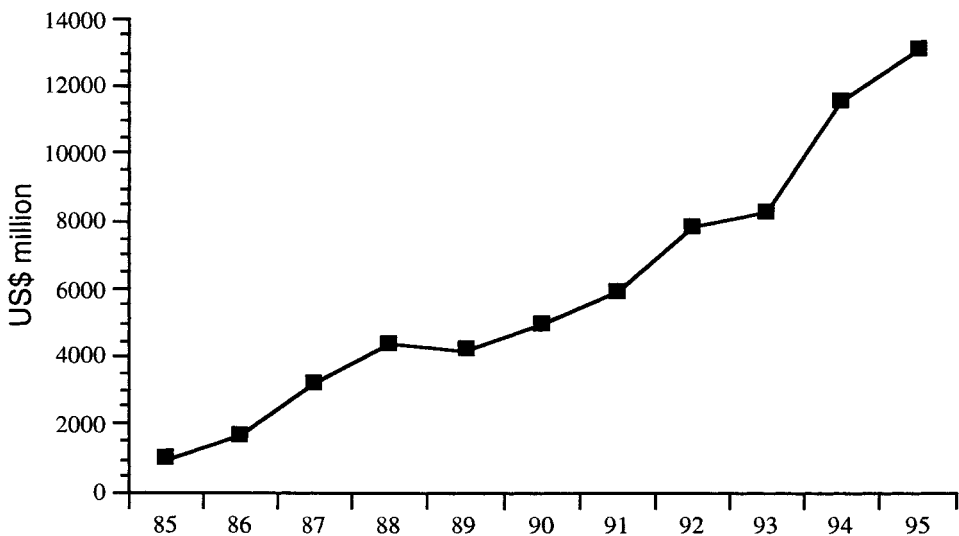


Figure 3. Computer hardware production in Taiwan, 1985–1995. (*Yearbook of World Electronics Data*, 1992, 1995; MIC/III, 1995).

Table 8
Taiwan's world market share and output of hardware products, 1994

Product	Domestic production (1000s of units)	Growth rate, 1993–1994 (%)	Total production, including offshore (1000s of units)	Share of world market (%)	Production offshore (%)
Monitor	14,391	8	24,028	56	40
Portable PC	2,057	59	2,057	28	0
Desktop PC	3,090	35	3,090	8	0
Motherboard	11,529	26	17,545	80 ^a	34
Scanner	1,663	75	1,663	61	0
Power supply	12,150	6	25,960	31	53
Graphics card	5,040	–1	8,770	32	43
Terminal	1,060	–24	1,060	22	0
Network card	6,100	60	6,120	34	0.3
Mouse	22,052	12	29,800	80	26
Keyboard	7,068	17	22,800	52	69
Audio card	1,986	331	1,986	11	0
Hub	310	95	310	18	0
Video card	472	88	472	24	0

Note. From MIC/III (1995).

^aShare of merchant market, which does not include production for internal use.

the degree to which domestic companies are involved (95% of exports were produced by domestic companies).

Taiwan's role in original equipment manufacturing (OEM) production is so great that one analyst dubbed it the "Krupps of the computer wars"—a reference to the German arms maker who supplied all the combatants in World War I. Taiwan does a large volume of OEM production for major PC brands such as Apple, Compaq, Dell, IBM, and Packard-Bell, averaging around \$400 million annually with each of these majors (Table 9).

In addition, Taiwan is OEM supplier to the global PC industry, including the leading computer companies in Europe and Japan as well as the United States (Table 10). And, as both of these tables indicate, OEM production is spread across a large number of products and firms, illustrating the breadth and depth of Taiwan's PC industry.

Taiwan's companies have to be agile to keep up with the rapidly changing technological and market environment. They were hit hard by the PC price wars of the 1990s, and remain precariously dependent on foreign sources of components and technology. Meanwhile, the appreciation of the NT dollar, combined with wage increases of 15–20% a year in 1989–1990, hurt Taiwan's price competitiveness across the board. Taiwan's computer industry had competed on the basis of low prices, and saw profits squeezed as costs increased and competitors lowered their prices (*Electronic Business Asia*, 1991). Many of the smaller producers were driven out of the PC market altogether.

However, Taiwan is nothing if not flexible, and its computer makers adapted to these challenges in several ways. Taiwan's companies have improved their engineering capabilities, allowing them to upgrade their products by designing new features into PCs and components. It is claimed that in Taiwan, the time required to take an engineering concept to volume production is the shortest in the world, at 90 days (Clifford, 1993). Taiwanese manufacturers are also said to operate with overhead costs of less than 10% of

Table 9
Taiwan OEM production for major PC vendors

Buyer	OEM product	Taiwan maker	1994 OEM expend. (US\$millions)	1995 OEM expend. (US\$millions est.)
Apple	Monitor	Tatung	\$300–400	\$300–400
	Notebook	Acer		
	PDA	Inventa		
	SPS	Delta		
Compaq	Monitor	ADI, Philips, TECO	\$400	\$500
	Mouse	Logitec, Primax		
	Notebook	Inventa		
	PCB	Compeq		
Dell	SPS	Lite-on, Delta	\$450	\$450
	Monitor	Lite-on, Royal		
	Notebook	Inventa		
	Motherboard	GVC, Lung Hwa, FIC		
IBM	PCB	Compeq	\$400	\$450
	SPS	Lite-on		
	Monitor	Sampo, Capetrionic		
	Motherboard	GVC, Elite, Lung Hwa		
Packard-Bell	SPS	Sun-Moon-Star, Delta	\$450	\$500
	Notebook	ASE		
	PC	Tatung		
	Motherboard	Tatung, GVC		
	Keyboard	BTC		

Note. From MIC/III (1995).

Table 10
Taiwan OEM production for PC vendors worldwide

Buyer	OEM product	Taiwan maker	Buyer	OEM product	Taiwan maker
AST	Notebook	Quanta	Hitachi	Monitor	Acer
DEC		Compal	Epson	PC Notebook	Unitron Arima, Compal
	Monitor	Philips Taiwan			
	PC	Lite-on			
	Alpha PC	DEC Taiwan			
Gateway 2000	Monitor	Elite	Philips	Notebook Monitor	Kapok Philips Taiwan
		Mag			
Sharp	Notebook	Twinhead	Siemens	Monitor	Kapok
NEC	Organizer	Cal-comp		Notebook	Quanta
	Monitor	Tatung	Vobis	Notebook	Clevo
	Motherboard	Elite		Monitor	Royal
	(98 series)				
Matsushita	Monitor	Parasonic, Taiwan	NCR	Monitor	Acer, TVM

Note. From MIC/III (1995).

sales, compared to 25–30% for foreign competitors, partly due to the excellent supply infrastructure and the limited levels of R&D and marketing carried out by Taiwanese firms. The latter provides an advantage in price competition, but is also evidence of dependence on foreign distribution channels and OEM production.

Taiwanese companies have moved into new market niches such as notebook computers while they are still highly profitable. To overcome the problems of labor shortages and increasing wages, firms are moving to automation and advanced production techniques such as surface-mount technology (SMT). Firms are also moving production of labor-intensive products offshore. The differential in labor costs is a factor of 10 between Taiwan and the mainland, and the mainland has a large supply of engineers and computer programmers (Table 2). The movement offshore is illustrated in Table 11. Offshore production was 24% of total production in 1995 and is expected to be 33% by 1997. This movement offshore, which is occurring among all Asian computer makers, is primarily in response to rising labor and facilities costs at home and increased price competition for personal computers in world markets.

Taiwan's computer makers continue to look for new ways to compete. Three trends appear particularly important: diversification, full-service OEM, and consolidation. Taiwanese firms are diversifying in both products and markets. Acer makes DRAMs in a joint venture with Texas Instruments, motherboard leader FIC is making notebooks, Elitegroup is focusing on scanners and semiconductors (in a venture with Mitsubishi), while scanner maker Umax has just licensed the Macintosh operating system to enter the Mac clone market. Other companies are expanding into new markets. Most notably, Acer has developed a worldwide marketing network (ranking number 1 in Mexico, for instance), and plans to list 21 subsidiaries on local stock markets by the end of the century (its "21 in 21" plan). Taiwan is also diversifying its OEM and components business as a number of major Japanese companies have begun to source in Taiwan or develop OEM relationships with Taiwanese companies. Fujitsu established an international procurement office in Taiwan in 1995 and plans to procure US\$2 billion worth of hardware through 1998. Epson, NEC, Sharp, and Hitachi are all involved in OEM relationship with Taiwanese companies. In fact, while Acer has pushed its own brand name, other companies such as Mitac have refocused on OEM production (Kraemer & Dedrick, 1996).

Taiwanese firms are also moving toward full-service OEM and ODM (original design manufacturing). OEM production used to involve a U.S. company coming to a Taiwanese company with a new design and contracting for production. Taiwan's OEM leaders, such as FIC, Mitac, Acer, and others, have now expanded their capabilities to include

Table 11
Domestic and offshore computer production (US\$ millions)

Hardware production	1992	1993	1994	1995	1996	1997
Total production	8,391	9,693	14,582	17,418	20,553	23,924
Domestic	7,418	8,002	11,579	13,139	14,584	16,043
Offshore	973	1,691	3,003	4,279	5,969	7,881
Offshore as percent of total	12	17	21	24	29	33

Note. From MIC/III (1995).

design, distribution, and service. Now a U.S. (or Japanese) company comes to Taiwan and is presented with a catalog of motherboard designs, and chooses the one that meets its system configuration requirements. If the Taiwanese company is producing the entire system, it may also distribute the finished product to the U.S. company's resellers and even provide warehousing, logistical and service support. The U.S. company might never actually take possession of the computer. Its only functions are marketing, channel support, and finance. This new arrangement puts a premium on set-up capabilities that go far beyond low-cost manufacturing. They include market intelligence, product design, logistics, and customer support. By developing these capabilities, the Taiwanese companies have increased their share of the value chain in the PC industry and created competitive advantage against competitors in other countries. Finally, Taiwan's companies have improved their quality and no longer have the reputation for the poor quality they had in the 1980s.

A very recent trend in Taiwan's computer industry has been an increasing concentration of production by larger companies. Taiwan's computer industry was built around nimble small- and medium-sized enterprises (SMEs), which could get to the market faster than the giants that dominated the industry in Japan and Korea. The PC industry has evolved to a point, however, where economies of scale are critical to success. Only large producers can get volume discounts on components, or offer the scale of production necessary to handle major OEM accounts. The same situation is true in components and peripherals such as motherboards and monitors. The result is that the industry is consolidating, with the top five producers accounting for the large majority of most product categories (Table 12). Some of the SMEs have grown into relatively large companies and have come to dominate certain market segments. For instance, over 70% of Taiwan's monitor production is accounted for by the 10 largest producers. Some of the larger companies, such as Acer, Mitac, and Tatung, have begun to achieve global brand name recognition. By 1995, Acer was the 8th largest selling brand of PCs in the U.S. market.

However, as shown in Table 12, the list of the top five includes different companies in most categories, with only a few companies such as Acer among the leaders in multiple product lines. So consolidation still does not involve industry domination by a few giant diversified firms, as is the case in Japan and Korea. The role of Taiwan's smaller companies is limited mostly to supplying components such as resistors, capacitors, screws, etc. This is still a critical role, however, as computer makers in Taiwan can literally order all the parts they need to develop a new design and have them delivered the same day. The companies hurt most by the consolidation are medium-sized firms that lack the size to compete in volume markets, but are too big to survive on small, irregular orders.

Still, the increased concentration is not turning Taiwan into another Japan or Korea. Even Acer and Mitac are still small companies compared to Hitachi, NEC, Samsung or Goldstar. And unlike the Japanese and Korean conglomerates, the Taiwanese firms mostly remain focused on the computer industry. It is not surprising that some industry concentration should occur as its industry matures. However, there is still a great deal of entrepreneurial energy in those companies and in start-ups trying to exploit new market opportunities.

Software and Services. Taiwan's software and information services industries are far behind the hardware industry in size and capabilities. Local production of packaged software was estimated at US\$166 million in 1993 and US\$215 million in 1994. Exports totaled about US\$45 million in 1993 and US\$56 million in 1994. Domestic companies also

Table 12
Computer output by major producers

Company	Desktop PCs	Portable PCs	Scanner (desktop)	Scanner (handheld)	Keyboard	Mouse	Switching power supply	Graphics card	Monitors
Acer ^a	Tatung	Quanta	Microtek	Mustek	BTC	Logitech	Delta	Great Tek	Acer
FIC	Mitac	Acer	Umax	Logitech	Silitek	SysGratton	Dee Van	TNC	Philips
DEC		Compel	Plustek	Primax	Acer	Primax	Lite-on	Prolink	ADI
2507		Inventa	Mustek	N/A	Chicony	Chic	Skynet	BTC	Tatung
3090		Twinhead	TECO	N/A	Monterey	Kye	Prior	Compro	Lite-on
		1082	480	962	14,136	23,644	21,720	2887	10,450
		2057	557	1106	22,800	29,800	25,981	8748	24,023
Top five	81%	53%	86%	87%	62%	79%	84%	33%	44%
Total industry									
Top five share									

Note. From MIC/III (1995).

^a List does not show ranking, companies are listed randomly.

provided US\$182 million in systems integration services in 1993 and US\$207 million in 1994 (USDOC, 1994a).

There are about 125 packaged software companies in Taiwan, employing 5600 people. Most are involved in PC applications, including Chinese system software and font generators, desktop publishing, word processing, and vertical applications for specific industries. The prevalence of pirated software hampers the development of a packaged software industry for the domestic market. Illegal copies accounted for 84% of PC software packages sold in Taiwan in 1993 according to the Business Software Alliance (1993).

In the past, growth in the software and services industry has been limited by a small domestic market, lack of intellectual property protection, and difficulties in raising capital. The tendency of government agencies to depend on III for their software and systems integrations needs is another problem. Development of large government networks and the NII is expected to create rapid growth for the software and systems integration industries, and III has pledged to contract more development to the private sector. The government has also been more serious about cracking down on software piracy since the United States threatened to invoke trade sanctions over the issue, and since Taiwan's own software industry has pushed for stronger enforcement.

Computer Use

Taiwan's installed base of computers and computing power is about twice the level of Korea, but lags well behind Singapore and Hong Kong. Investment in computer products and services in Taiwan was the lowest of any of the East Asian NICs in 1992, measured by computer spending as a percent of GDP (Table 13). Taiwan's spending increased at a rate second only to Korea among the NICs from 1983 to 1992.

Figure 4 shows the Taiwan computer market by product category. The relatively low levels of spending on software and services reflect the often-stated claim that Taiwanese

Table 13
Computer use in Asia-Pacific countries

Country	Investment		Installed base	
	Investment in computers ^a as percent of GDP, 1992	Average annual growth rate (%), 1983–1992	Number of computers per 1000 people	MIPS ^b per 1000 people
Japan	1.99	11.85	97	199
Singapore	1.42	17.01	125	241
Hong Kong	0.84	12.85	101	159
Korea	0.87	22.63	37	70
Taiwan	0.77	19.51	74	150

Note. From CRITO Database; Juliussen and Juliussen (1994).

^aHardware, software, and services.

^bMillions of instructions per second, a measure of computing power.

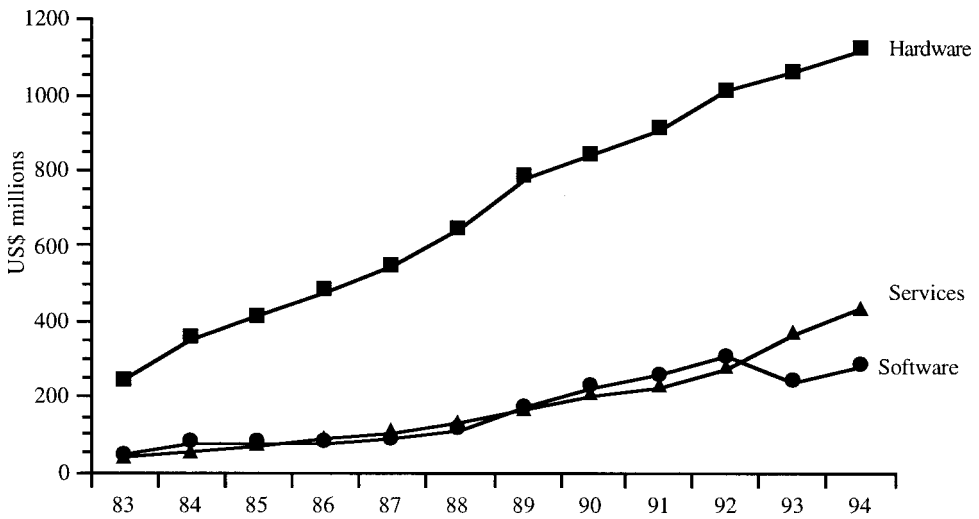


Figure 4. Taiwan computer market by product category, 1983–1994 (CRITO Database).

business people are unwilling to spend money on services and expect software to be bundled with hardware.

Figure 5 shows that the public sector has led the way as the largest user. This is partly the result of Taiwan's strategy of government paving the way for computer industry growth by creating demand. It is also because most small Taiwanese companies have lacked the resources for investment in computerization and have not appreciated the value of computers as a business tool. In recent years, computer investment by the private sector has grown rapidly as the cost of computers dropped and as user companies grew

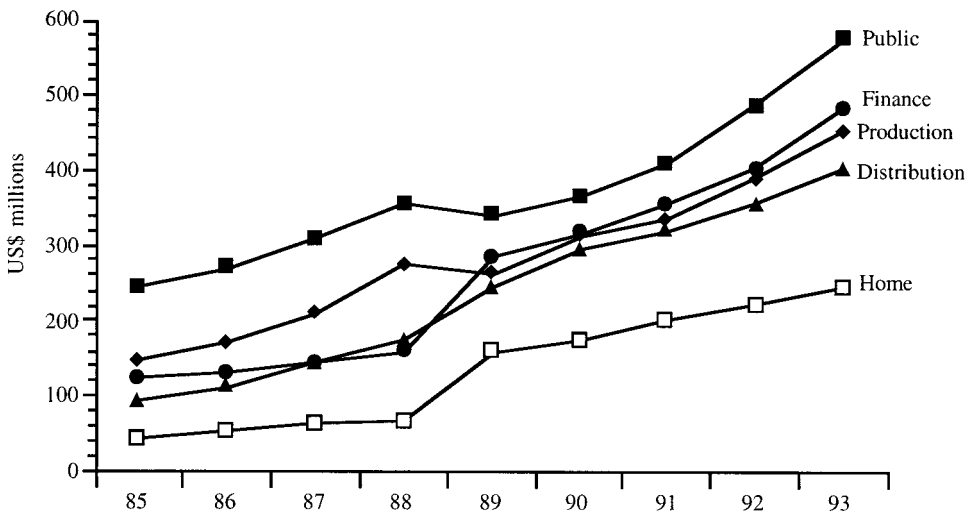


Figure 5. Taiwan computer market by user sector, 1985–1993 (CRITO Database).

larger and gained technological sophistication. The home market is also growing rapidly, accounting for over 10% of total sales.

Conclusions

The two-way relationship between environment and policy, posited in our conceptual framework, is clearly illustrated in the foregoing history of Taiwan's computer industry. The Taiwan government helped create a decentralized industry structure throughout the economy by its policies in the 1950s and 1960s. When it began promoting the computer industry in the 1980s, it had an industry structure in place that was well suited to the decentralized structure of the international PC industry. The government took advantage of the strengths of that structure and designed policies that would help compensate for its weaknesses. The combination of a favorable industry structure and effective government policies helped Taiwan become the fourth largest producer and exporter of computer hardware in the world by 1994.

Taiwan's success might best be considered in contrast with other countries in the Asia-Pacific region. In contrast to Korea, Taiwan has been able to weather and adapt to the brutal market pressures of the late 1980s and early 1990s. Korea's computer production and exports declined dramatically in the early 1990s and Korea's PC industry has failed to move beyond simple assembly of PCs and production of monitors (Dedrick et al., 1996). Even Japan's giant computer manufacturers have seen their revenues and profits hit hard by price competition and the shift in demand from mainframes to PCs. Singapore is a major export platform for MNCs, but has limited involvement by domestic firms (Gurbaxani et al., 1991). Hong Kong's computer industry has shifted much of its labor-intensive production to China, and has generally failed to develop its technological capabilities (Kraemer et al., 1994).

How is it that Taiwan's computer industry has been able to continue to grow and upgrade its technological capabilities while others have floundered? An adequate explanation must include both environmental and policy factors. In particular, we focus on industry structure and entrepreneurship on the one hand, and a coordinated, pragmatic approach to computer policy on the other.

Industry Structure and Entrepreneurship

Taiwan's industry structure is well suited to the international personal computer industry. The open architecture created by IBM in the PC industry lowered financial and technological barriers to entry and created a market for standardized components and peripherals. In the earlier mainframe computer era, smaller companies were largely shut out of the market by IBM's market dominance and its strategy of producing a large share of components and peripherals in-house. The PC revolution created a new horizontally segmented industry structure, with opportunities for many companies to compete in fast-growing market niches throughout the production chain. A company could build a better or cheaper component, based on openly available technical standards, and find a buyer for it.

These conditions fit well with Taiwan's computer industry. The many SMEs in the computer industry are supported by a deep and wide supply infrastructure that extends from basic parts and components in the plastics, metal working, chemicals, and electronic industries to subassemblies in the PC industry. These basic industries, plus the subassemblers of system boards, keyboards, monitors, power supplies, printed circuit boards, integrated circuits, and cases/housing in the PC industry, are located in a 60-km geography

from Taipei to Hsinchu that provides close cooperation between suppliers and manufacturers, personal networking between engineering and technical staff, natural just-in-time (JIT) or near-JIT delivery cycles, ample second sources in the event of supply problems, and immediate engineering and technical support. No order is too small or insignificant for Taiwanese companies, who take business that larger competitors ignore and provide the fastest turnaround in the industry. Over time, they have been able to produce more sophisticated products and on a larger scale, but their strength has remained in flexibility and responsiveness.

The key to the flexibility and responsiveness is Taiwan's entrepreneurial corporate culture. Many computer firms started as family companies or small partnerships. The top management has usually had an engineering background and, over the years, has been involved in all key areas of the business from design to purchasing to manufacturing to distribution. The senior manager usually travels extensively, networking with customers, suppliers, and competitors, as well as attending numerous professional and business conferences in an effort to stay abreast of both technology and markets. Decision making has been highly centralized in the senior manager, or a small team, with communication between executive and line management direct and by voice. Because of this broad experience, extensive networking, and centralized decision making, Taiwanese firms have been able to respond quickly to both demand and supply opportunities as they arise.

The emphasis placed on an entrepreneurial culture in Taiwan's PC industry is illustrated by Acer's recently announced plan to break itself up into 21 public companies by the twenty-first century in an effort to retain an entrepreneurial culture. Acer Chairman Stan Shih made the move because he felt that it would motivate employees to work harder by giving them a stake in the company. Quoting a familiar Chinese saying, he said, "I would rather be the head of the chicken than the tail of the cow." Acer plans to list the units on local stock exchanges in the countries in which they operate, keeping a minority stake for the parent company. This strategy is aimed at allowing the units to raise adequate capital for their needs and operate with substantial independence while maintaining some of the advantages of size (e.g., brand recognition, technology sharing) through association with the parent company. It remains to be seen how this arrangement will work in practice, but it is an interesting approach to encouraging rapid growth while maintaining flexibility.

The presence or lack of entrepreneurial energy in a country is not a phenomenon that has been investigated extensively or that is well understood. However, in Taiwan, the government has supported small business with subsidies that are not available to companies above a certain size. This creates an incentive to keep companies small by spinning off activities and creating new companies, thus reinforcing the entrepreneurial culture. The prevalence of small firms in the computer industry has caused problems in achieving economies of scale in production and R&D, but it has also encouraged firms to continually seek new product niches in which they can make a profit.

Flexible, Coordinated Technology Policy

Government policy has been aimed at complementing and supporting, rather than replacing, the efforts of the private sector. There has also been an effective flow of information between the public and private sectors. Information from the private sector has enabled government to make policies that address the needs of industry, such as facilitating technology transfer and funding research through ITRI, ERSO, and III that the private sector could not afford. Government institutions, such as MIC, have provided industry with in-

formation on new technologies and market opportunities. Government has also provided for the development of critical human resources needed by industry by emphasizing the production of engineers and computer professionals, the training and certification of existing staff, and the recruitment of high-level, experienced overseas Taiwanese to help develop its information industries.

Taiwan has also been able to achieve a relatively high level of cooperation among government agencies with responsibility for computer policy. Unlike Japan and Korea, which have become bogged down in recent years by bureaucratic infighting, Taiwan has been able to coordinate the efforts of economic, scientific, communication, education, and executive agencies. This is not to say that there is no competition or jealousy among institutions. The calls by other agencies (and private companies) for the breakup or scaling down of ITRI and III belie that notion. However, compared to many countries, Taiwan has been able to develop and implement a coordinated strategy for computers without bureaucratic infighting.

Taiwan's government-sponsored institutions and private industry have been very nimble in responding to changes in international markets and to the rapid pace of technological change in the computer industry. Institutions such as ITRI, ERSO, and III have so far avoided getting bogged down in long-term, inflexible plans and projects. Instead they have generally responded to the more immediate needs of industry and government.

Taiwan has also exhibited flexibility in its international orientation and links to multinational corporations. Taiwan built its electronics industry, and then its PC industry, on the basis of relationships with multinational corporations. The industry was export oriented from the beginning, partly in response to government incentives, but also due to the small size of the domestic market. Taiwan could not produce just for its domestic market and develop a successful PC industry. The government supported the industry internationally by providing market intelligence, facilitating technology transfer from abroad, and encouraging investment by foreign computer makers in Taiwan.

Future Challenges

In spite of its success, Taiwan's computer industry still faces serious challenges if it is to maintain its pace of growth. Its products are known for low price, but price competition in the industry and rising labor costs at home are putting a squeeze on profit margins. Dependence on Japanese companies for critical components puts Taiwanese companies in a vulnerable position.

As Taiwan's companies grow larger, they are faced with the need for a more focused approach to R&D and product management. Profit margins for computer hardware are thin for companies that do not control critical technologies. Taiwan needs to continue to improve its technological capabilities and develop strategies such as original design manufacturing in order to stay competitive. Survival as an OEM can be precarious, as customers can always look for cheaper suppliers. Taiwan's shift to a full-service OEM/ODM producer has bolstered its position in the market. Eventually, more companies may decide to follow Acer's lead in developing their own brand-name products for export. Creation of brand-name awareness is expensive, but it allows companies to control their distribution channels and create demand from end users.

Taiwan is still far behind the industrialized countries, and even behind the other East Asian newly industrialized economies, in its level and sophistication of computer use. The entire economy would benefit from greater investment in computer use, which has been shown in several studies to have a high rate of return at both the firm level and the

national level (Brynjolfsson & Hitt, 1993; Kraemer & Dedrick, 1994; Lichtenberg, 1993). Increased investment in computer use would also spur domestic demand for software and services, which are often more profitable than hardware production. There is also tremendous potential for the export of Chinese-language software throughout Asia, and an especially large market if trade relations are liberalized between Taiwan and the mainland. If Taiwan's SMEs were to take to software production as well as they have to hardware, Taiwan could become a leader in Asia's software industry, although the continued problem of piracy throughout Asia makes this difficult.

In spite of the problems it faces, Taiwan is probably Asia's best positioned country for continued success in the computer industry. Its industry structure is well suited to the global computer industry and shows great adaptability as illustrated by recent trends toward diversification, full service OEM and consolidation. It is rapidly developing its technological capabilities to stay ahead of low-cost competitors in the region. And, it is already in the process of globalizing its own production to lower costs and gain market access through investments in China, Southeast Asia and North America. Taiwan's plans for NII development, if carried through, should help maintain its competitive position as global production chains and marketing channels are increasingly connected electronically.

Note

1. The exchange rate of NT\$:US\$ is about 25:1.

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